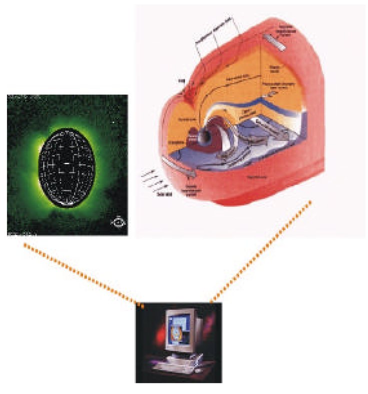

Comparative Modeling of Magnetospheric and Ring Current Dynamics for the July 2000 Space Weather Event

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Abstract

Global modeling of the magnetosphere demonstrates the operation of the Community Coordinated Modeling Center (CCMC) applied to recent space weather events. We perform simulations of the whole magnetosphere dynamics using data from GEOTAIL for the July 15 event. During this events we show the reaction of the Earth's magnetosphere and ionosphere in a comparison of two sub-events defined by fundamentally different solar wind conditions. The adaptive grid magnetohydrodynamic (MHD) model BATSRUS is employed to provide the magnetic filed configuration and current for the ionospheric electric potential solution that is in turn used to provide the ionospheric boundary conditions for the inner magnetosphere.

The results of the simulations may then be compared to satellite or ground observations for the determination of accuracy needed in future operational forecasting.

Keywords: magnetotail, numerical modeling, solar wind/magnetosphere interactions, storms and substorms, numerical simulation studies plasma waves and instabilities

Introduction

The events of July 15, 2000 are generated by the impact of several interplanetary disturbances. These disturbances strongly affect the magnetosphere-ionosphere system leading to a sequence of space-weather events.

In order to investigate the dynamical response of the coupled magnetosphere-ionosphere system following the impacts, we utilize the BATSRUS global MHD model to simulate the sequence of the events. This investigation is done at the CCMC as a science-based test of the viability of the BATSRUS model as a space-weather prediction tool. GEOTAIL data (courtesy L. Frank and T. Nagai) are used as solar wind input parameters.

In the paper,we present results from this simulation, as well as a preliminary scientific analysis. We focus on two segments of the overall, nine-hour long event: The period around the first shock impact, and the period around the extremely strong negative Bz excursion in the solar wind. The emphasis in the analysis is on the magnetospheric dynamics as well as the ionospheric response.

Input data

The July 15 event as seen by GEOTAIL is shown in this graph:

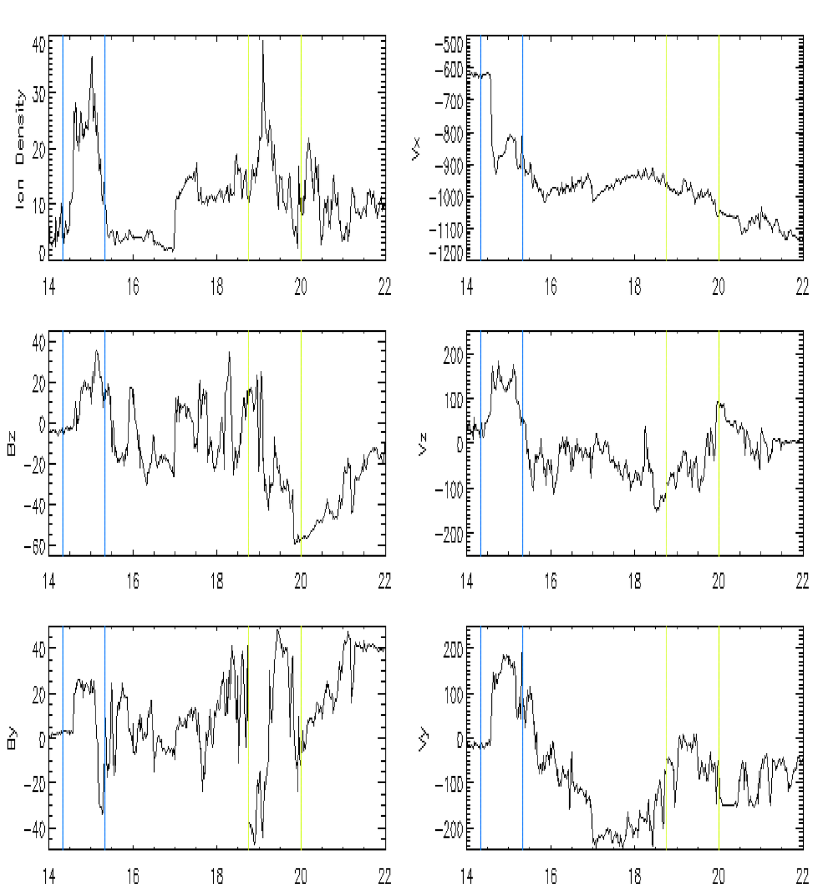


Figure 1: GEOTAIL data (CDI and MAG)

- Section 1 (enclosed by blue lines): Massive magnetic cloud with high density and moderately high B_y and B_z increases followed by a sharp turn in B_y.
- Section 2 (enclosed by yellow lines): large negative excursion of B_y and negative turn of B_z is accompanied by spike in plasma density and then followed by return of B_y to large positive values. B_y returns to zero as B_z becomes even stronger negative.

Global magnetospheric view

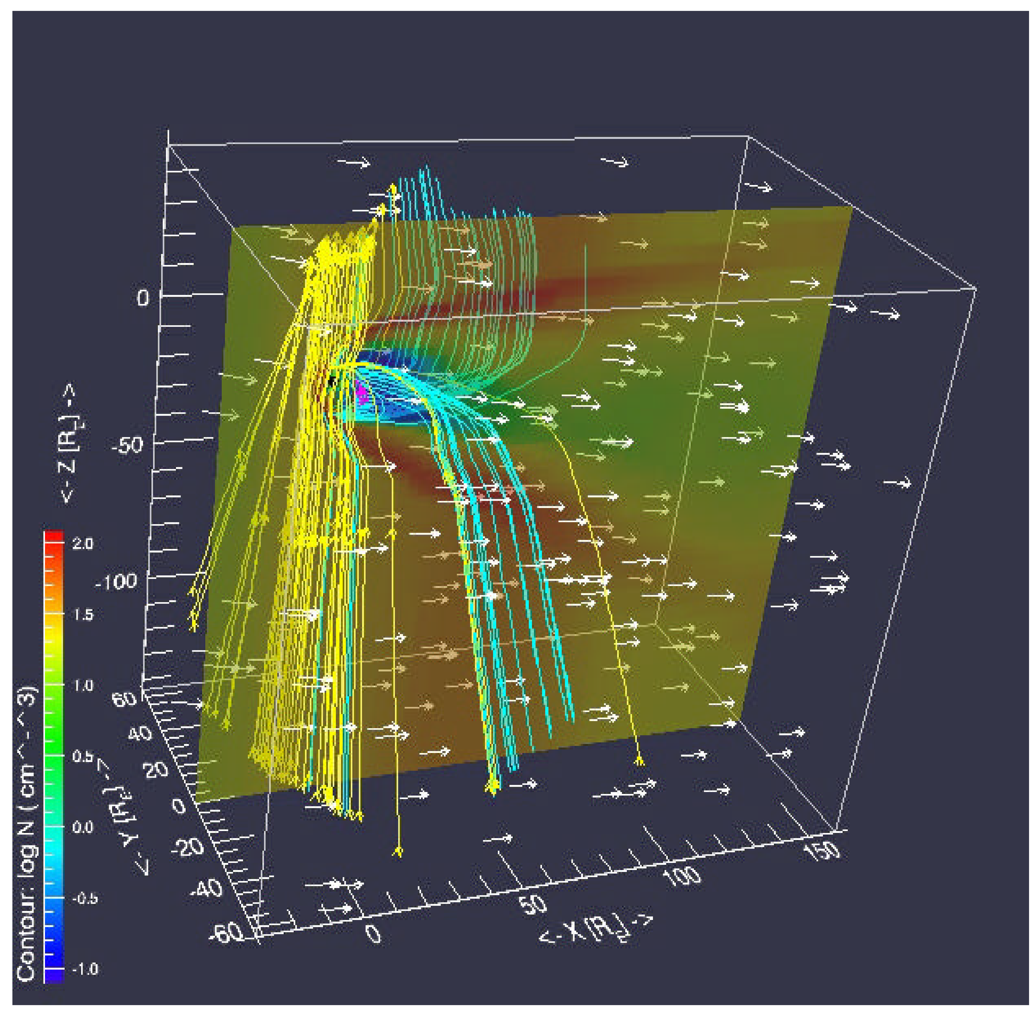


Figure 2. Global field line topology.
Shown are magnetic field lines together with a meridional cut (Y=0) through the density (N) distribution. The arrows indicate the plasma velocity at random locations.
Field lines are colored according to their topology
purple: closed lines in inner magnetosphere,
blue: half-open cusp field lines,
yellow: solar wind field lines.
The colored cut plane Y=0 is transparent and duller-colored sections of field lines are behind the plane
This particular plot shows change of the solar wind By entering our simulation around 15:00 UT from positive to negative.

(a)
(b)
(c)

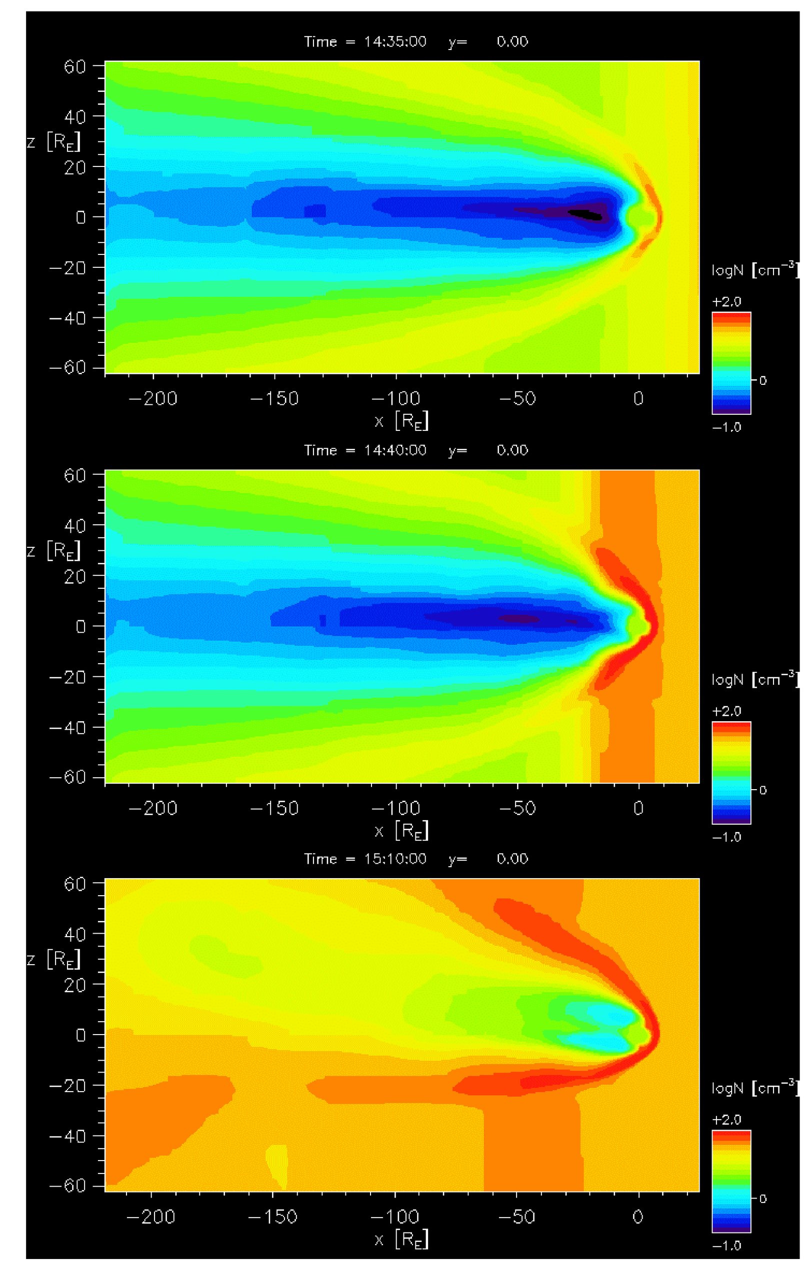


Figure 3. Magnetotail during the first cloud event.
Y=0 cut through the entire simulation box (a) before the first density increase, (b) when the first shock arrives and (c) while the density passes the magnetosphere.

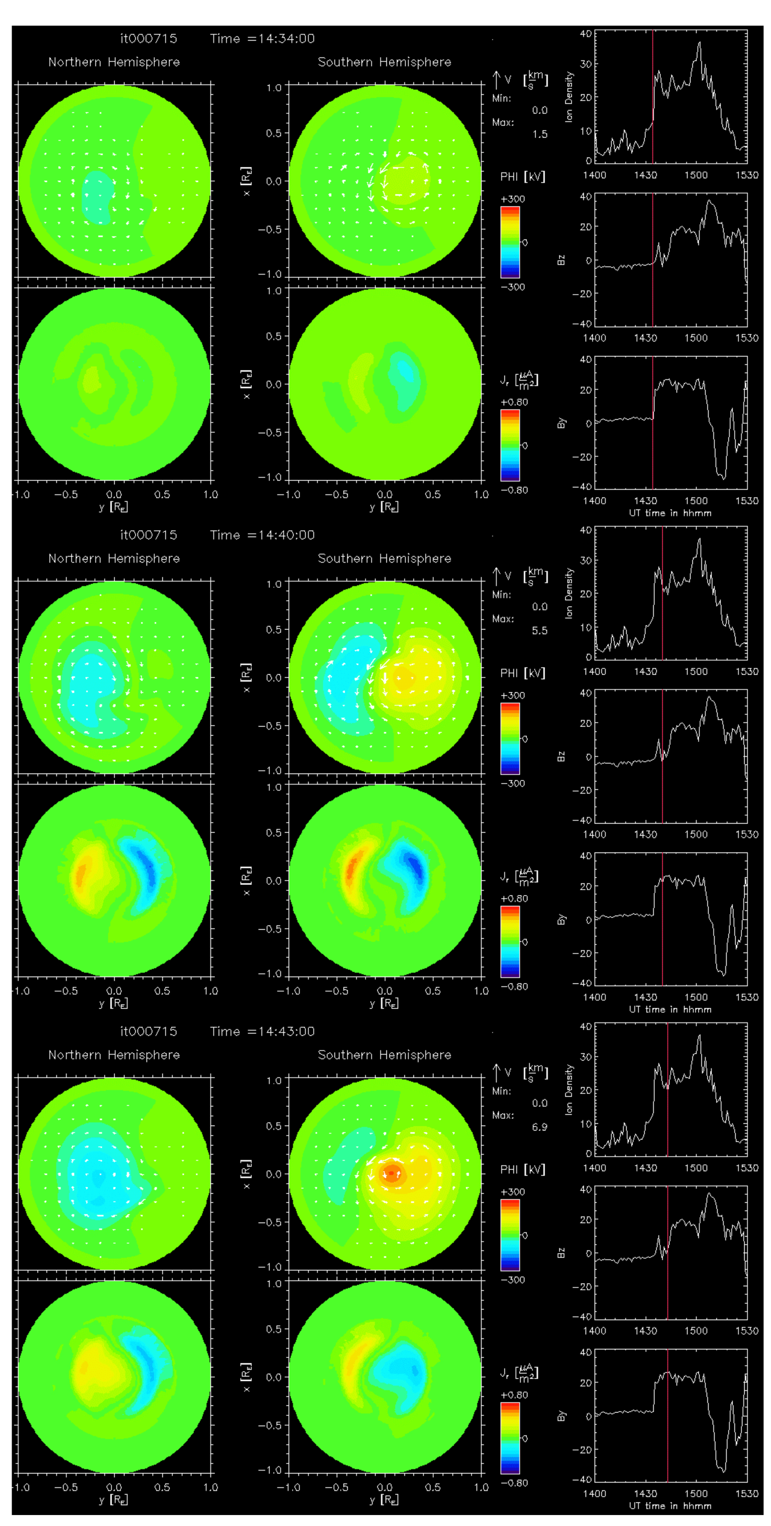
Both, a 3D field line movie of the first 80 minutes and a cross-section movie of 180 minutes of simulation starting at 14:20 UT are shown.

Ionospheric response: Time section 1 (14:20 – 15:20 UT)

Figure 4: 1st shock arrival (14:35):

Density increase with both By jumping to +20 nT.

(a)
(b)
(c)



The ionosphere responds after a 4-5 minute delay including convection time after strong changes in the solar wind pass at 24 R_E, the upstream simulation box boundary.

Figure 3a and 3b show the related global views associated with Fig. 4a and Fig. 4b, respectively. The time in Fig. 3c corresponds to Fig. 5b.

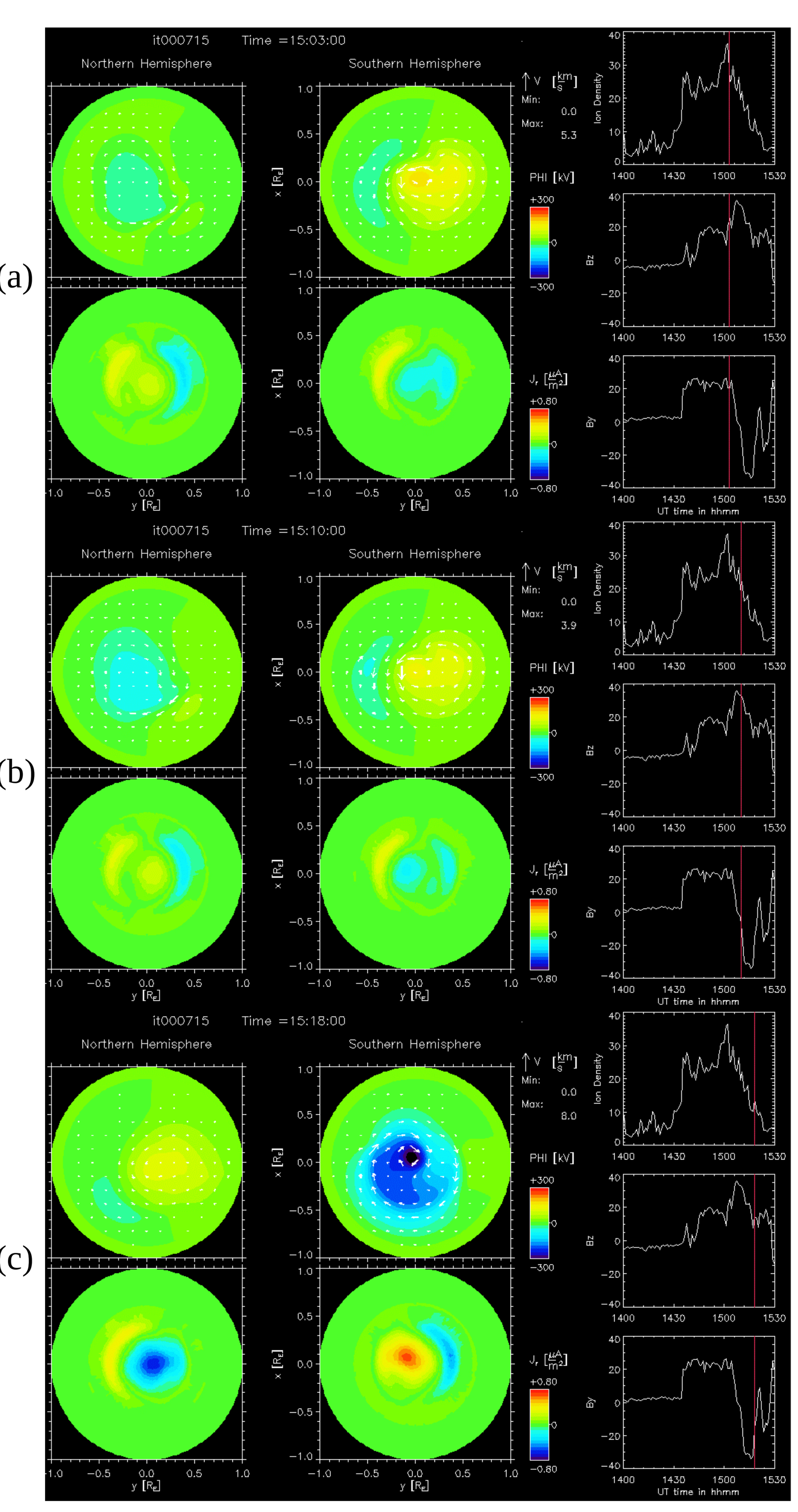
The increase of By from near zero to over 20 nT generates strong asymmetry in ionospheric currents and potentials (Fig. 4).

Reversing B_y reverses the electric potentials as the pattern of the incoming currents is mirrored (compare Fig. 4c to Fig. 5c).

Figure 5: Trailing side of density bulge (15:10):

Strong density drop with reversal of B_y to –40 nT.

(a)
(b)
(c)



Time section 2: (18:48 – 20:11 UT)

Magnetospheric environment:

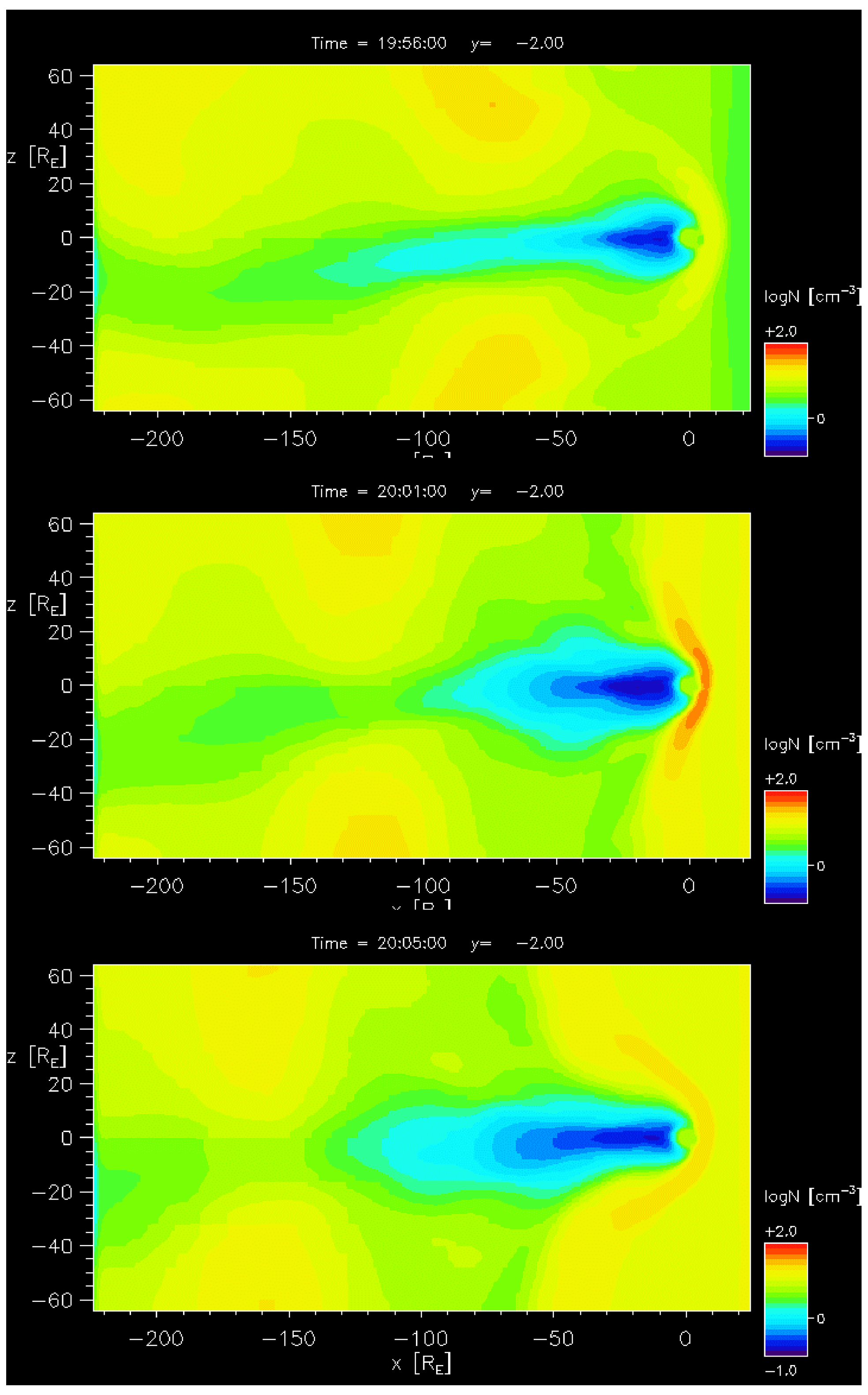


Figure 6: The varying volume in the magnetospheric cavity changes the currents that flow into the ionosphere with the varying solar wind plasma density as seen from Fig. 8.

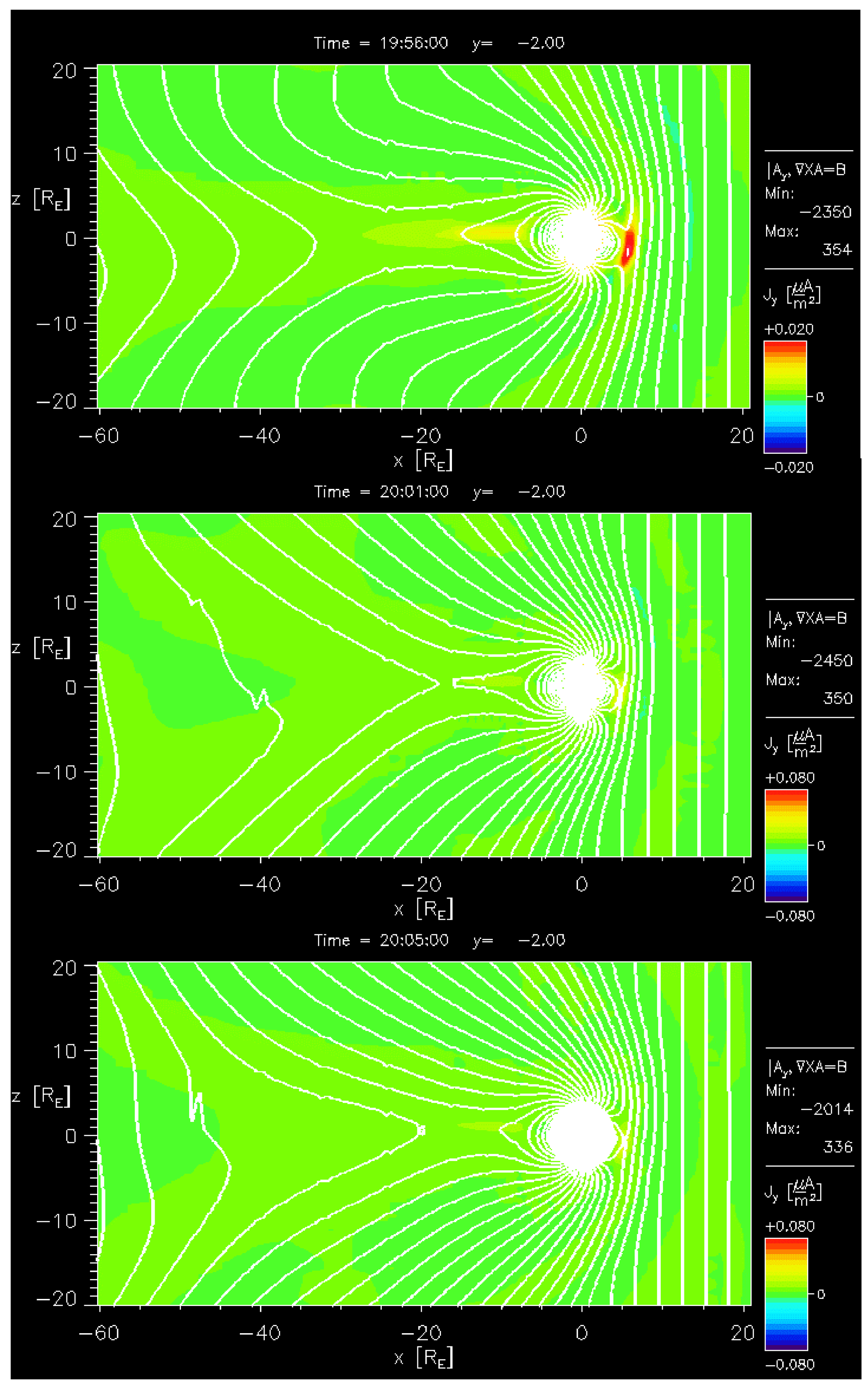


Figure 7: Fieldlines andcurrents J_y near the Earth for the same times as in Fig. 6. The tail experiences rapid changes in volume due to reconnection.

Ionospheric response:

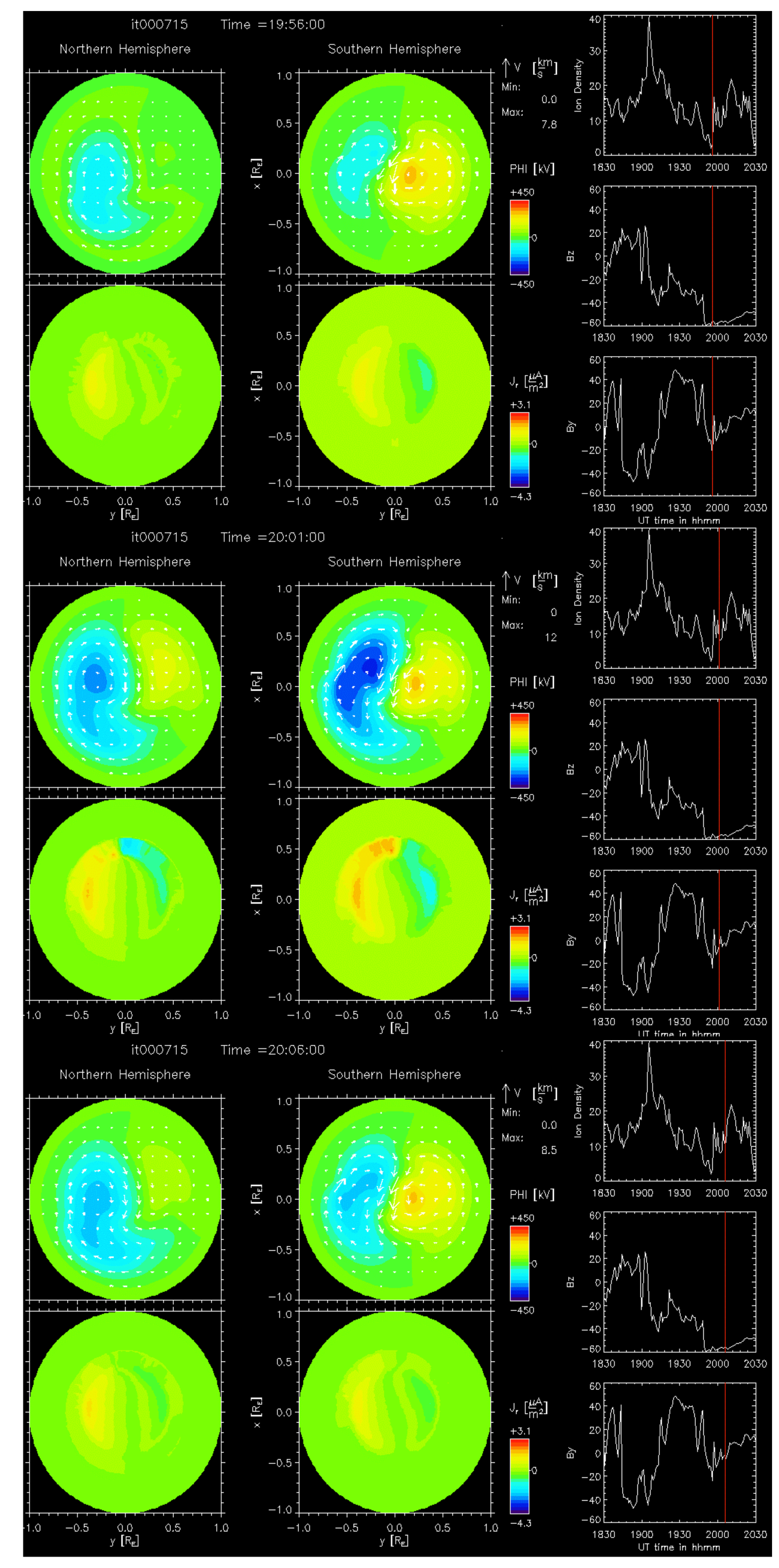


Figure 8: The ionospheric response is mainly following the solar wind density. B_y is relatively weak and B_z is the dominant magnetic field component leading to a symmetric current and potential pattern in the ionosphere. The times correspond to the panels of Fig. 6 and 7.

Results

For both time sections the ionosphere follows the input with a delay of about 4 minutes (including convection time from the simulation box boundary (GEOTAIL location). Rapid changes of the ionospheric electric potential and flow patterns are triggered by the changing electric field-aligned currents in the near-Earth magnetosphere.

We find the characteristic clockwise convection pattern dominating with B_y<0 and counter-clockwise convection with B_y>0.

For a period of weak B_y the ionospheric currents and electric potentials quickly return to a symmetric state. We found that the ionosphere responds directly to solar wind plasma density changes with B_z strongly southward.

Future Work

Significant events with sufficient observational coverage can be used to challenge the accuracy of numerical simulation models.

For the present simulations the exact sources of the currents feeding the ionosphere may have to be determined as well as effects of numerical resolution on the results. The accuracy of the near-Earth magnetic field solution may be tested directly in conjunction with ring-current particle flux models.

For future now-casting and forecasting capabilities the models must be reliable, fast, robust and must provide ease of use and data transfer and interpretation.

Operational space weather prediction models will have to perform faster than real-time with products, e.g. ionospheric, ring-current, and other near-Earth magnetospheric features being predicted in a consistent manner.

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